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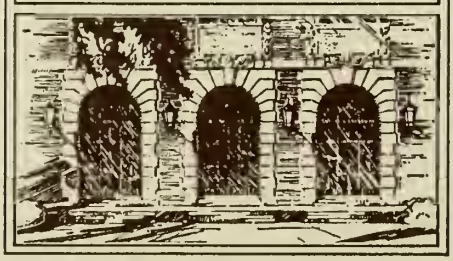

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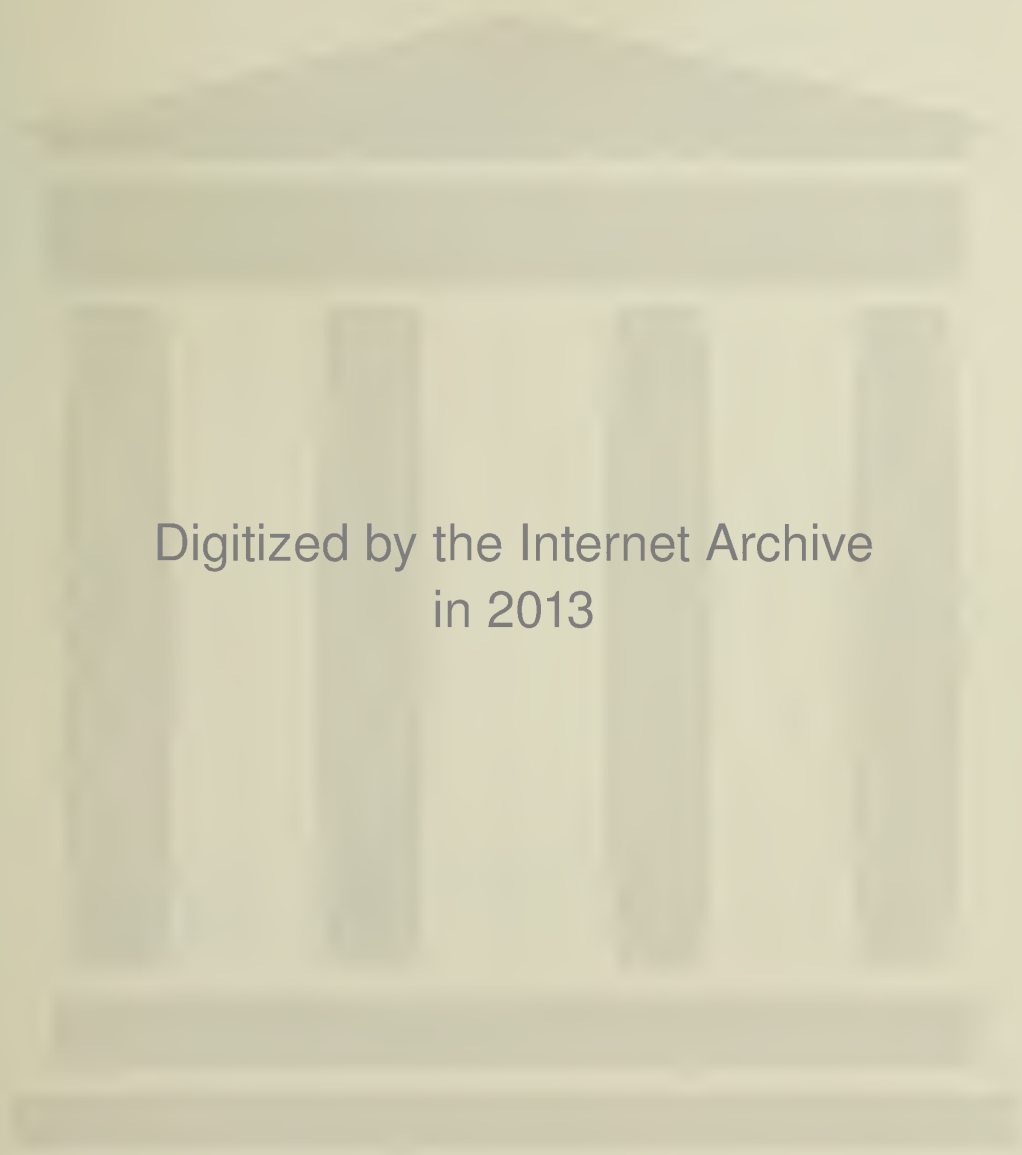

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REPORT NO. 135

MODEL OF PARTIAL SWITCHING IN POLYCRYSTALLINE FERROMAGNETICS

by

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March 19, 1963

The method of partial switching of ferrite memory cores in digital computer memories has come into extensive use since the advantages of greater speed and lower energy consumption were pointed out.[1-3] No theoretical or conceptual explanation of the process of partial switching has been presented, however.

In this paper, some generally known properties of domain wall motion and polycrystalline materials are brought together to provide a heuristic explanation of the microscopic partial switching process. Formulation of these concepts results in a simple, accurate macroscopic model. The results are striking in view of the microscopic complexity of partial switching phenomena.

BACKGROUND

The basic mechanisms of domain nucleation and wall growth in polycrystalline ferromagnetics have been elucidated by Goodenough[4] and by Menyuk and Goodenough.[5] It was found that domain walls are nucleated at a set of centers when the applied field intensity, H, exceeds a certain value, H_n, the nucleation field. The domain walls are then driven outward with a velocity proportional to $(H-H_o)/S$ where H_o is the "threshold field intensity" and S is the "switching constant."

A viscous damping force opposes the expanding walls until collision and mutual annihilation occurs. The magnetization is reversed in the wake of the moving walls which are usually assumed to be 180° walls.

If a driving field of sufficient amplitude and proper direction is applied to an initially saturated specimen, then the specimen undergoes "full switching" which may be truncated after a time leaving the specimen in an intermediate flux state. Figure 1 illustrates an idealized cross-section of the magnetic material at some instant during switching from an initial saturated state. If the driving field is truncated at that instant, it has been demonstrated that the domain structure is stable and, therefore, remains substantially unchanged after cessation of the driving field.[5]

If a driving field is then applied in the opposite polarity to the original drive, a flux reversal occurs which exhibits voltage-time curves with faster switching and greater peak amplitude, per unit drive amplitude, than the full switching curves. These are the partial switching curves which appear typically as illustrated in Figure 2.

DEVELOPMENT OF THE MODEL

Basic Assumptions

Consider a magnetic specimen in a saturated state, $-\Phi$. If a rectangular driving field, H_w, is applied for time, T_w, then a certain mean radius of domains, $< R >$, would be established for those domains whose walls have not been annihilated prior to T_w.

Then,

$$< R > = K_w T_w \qquad (1)$$

where $K_w = (H_w - H_o)/S$, the domain wall velocity in seconds^{-1} and $|H_w| > |H_o|$ but sufficiently small that rotational switching is negligible. (Here and hereafter, the subscripts "w" and "r" denote "write" and "read" by correspondence with the operations of a partial switching core memory.)

If a driving field, $H_r = -H_w$ is then applied to the specimen, the wall in existence at time T_w ("established wall") will move back toward the nucleation center from which it originated. It is assumed that a new wall is nucleated and moves outward ("renucleated wall"). The two counter-moving walls, traveling at equal velocity, are mutually annihilated when they collide at time $< T_w/2 >$ and radius $< R/2 >$[6] as indicated in Figure 3.

Therefore, during the application of H_r, the flux reversal is attributed to two components, namely,

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(1) the renucleated walls which move outward and repeat the flux reversal (except for sign) which occurred during application of H_w and

(2) the established walls which retrace, in reverse order, the mean configurations taken during application of H_w.

These two components of flux reversal are modified by collision of the renucleated and established walls.

It is well known that physical imperfections and magnetostrictive effects hinder wall movement.[7] Wall velocity variations and even wall segmentation have been directly observed in thin film measurements.[8] On this basis a dispersion of walls is assumed which causes the wall length to be annihilated non-deterministically during collision of the counter-moving walls. In the absence of direct data, it is assumed that the collision is governed collectively, if not for individual domains, by Gaussian statistics.

Formulation of the Model

Assume that a full switching curve is given by $V(t,K_w)$ and that the switching is truncated at $t = T_w$. Then the partial switching curve for the same magnitude of drive field, $|H_r| = |H_w|$, is:

$$v(t_r,K_r) = \left\{V(t_r,K_r) + V[(T_w-t_r),K_r]\right\} \cdot [1-G(t_r,T_w/2,\sigma)] \qquad (2)$$

where $G(t_r,T_w/2, \sigma)$ is a Gaussian distribution in the variable t_r, with mean value $T_w/2$ and standard deviation, σ.

The first term on the right side of equation (2) corresponds to the two components described in the preceding section. The second term specifies the statistics of collision of the counter-moving walls.

A family of experimental and model-predicted curves are displayed for comparison in Figure 4.

The value of σ is empirically assigned as $\sigma = 0.2t_p$ where t_p is the peaking time of the full switching curve, $V(t,K_w)$. This value is known to hold uniformly over the range 0-100% switching and for drives up to $4H_o$ in two standard varieties of Mg-Mn memory cores.

The graphical construction technique equivalent to Eq. (2) is demonstrated in Figure 5.

CONCLUSIONS

A model of partial switching has been developed which has the following properties:

1. It depends only upon knowledge of the full switching voltage-time waveform for determining the partial switching family (0-100% switching).

2. It is independent of the origin of the full switching waveform, i.e., whether theoretical or experimental, and need not depend upon knowledge of the parameters H_o or S.

3. The corresponding graphical technique for generating the partial switching waveforms is extremely simple.

4. The model is based upon well known concepts of domain wall motion and the histology of polycrystalline technical materials.

The accuracy of prediction of the partial switching waveforms is commensurate with experimental accuracy in all cases which have been tested.

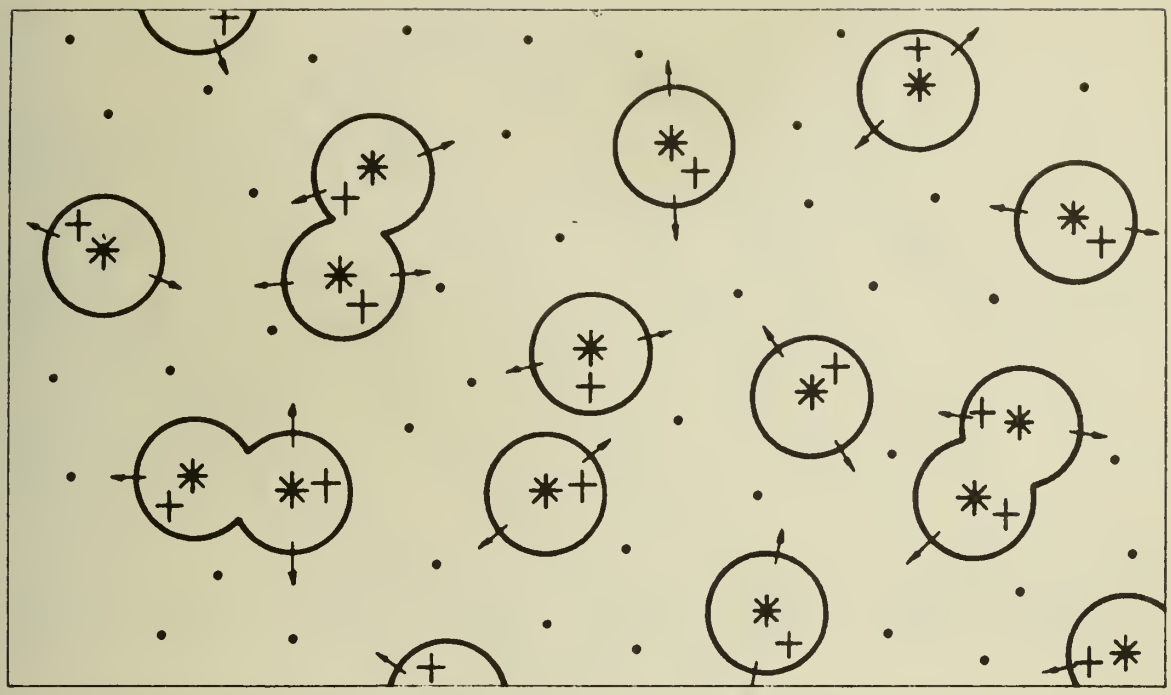
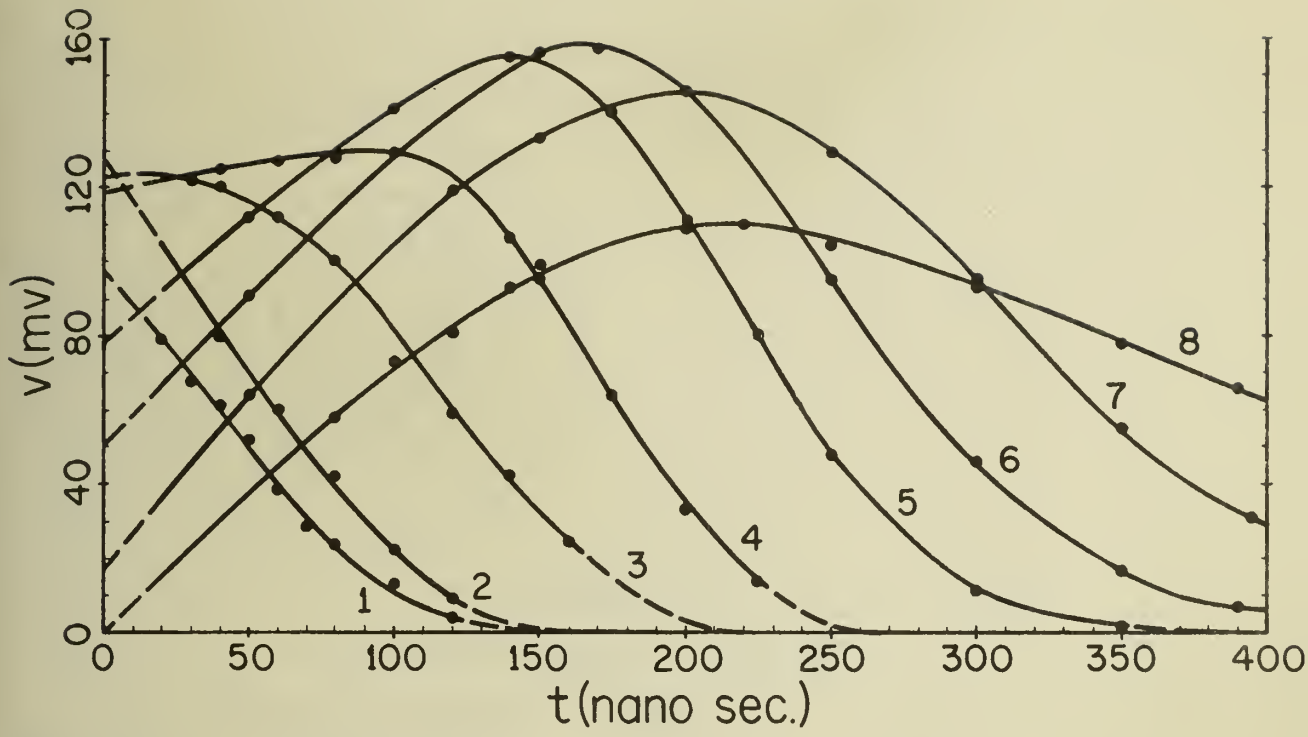


Figure 1 - Idealized Domain Cross-Section
During Full Switching



ACTUAL CONDITIONS:

Tw = 200 ns.

Fr = 515 ma. - turns (read mmf.)

CURVE Fw (write mmf. in ma. - turns))

① — 430
② — 465
③ — 538
④ — 615
⑤ — 704
⑥ — 772
⑦ — 858
⑧ — 1610 ≅ FULL SWITCHING

Figure 2 - Typical Family of Partial Switching Curves

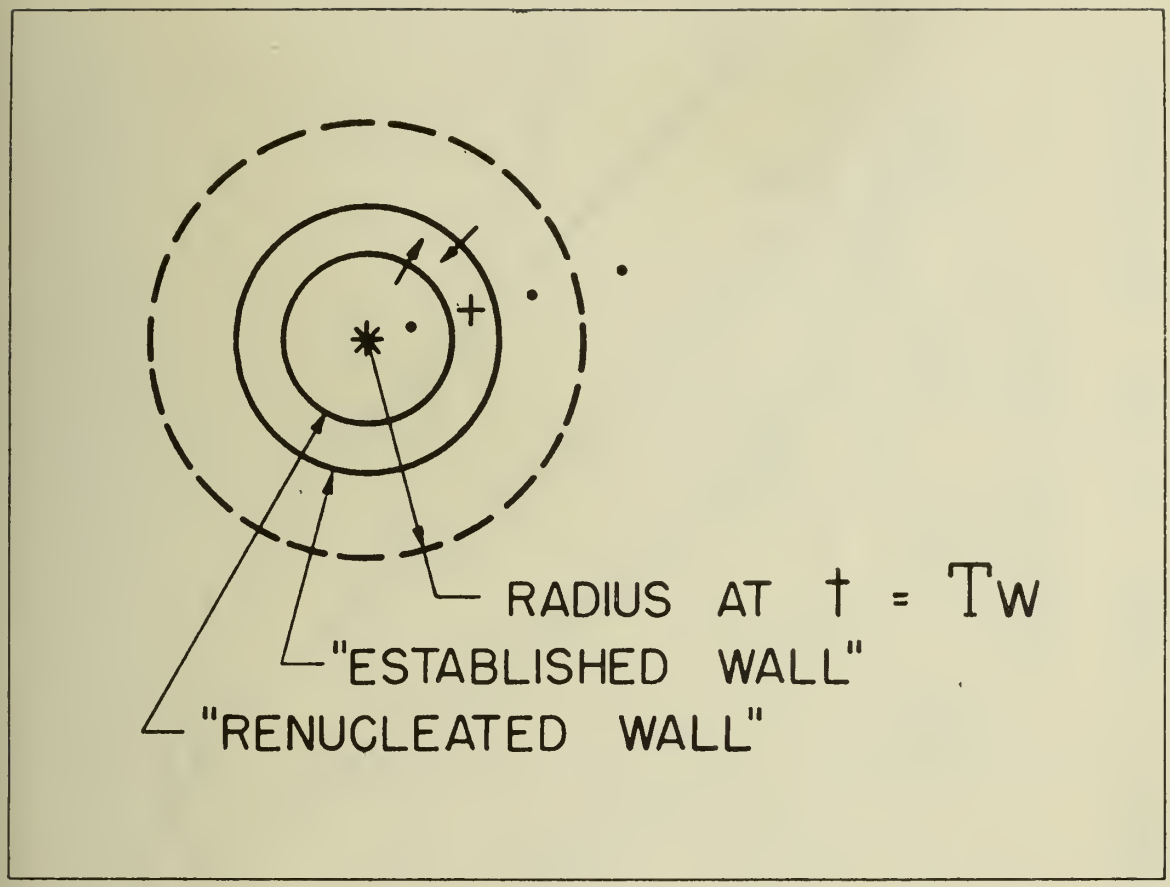


Figure 3 - Idealized Counter-Moving Walls
During Partial Switching

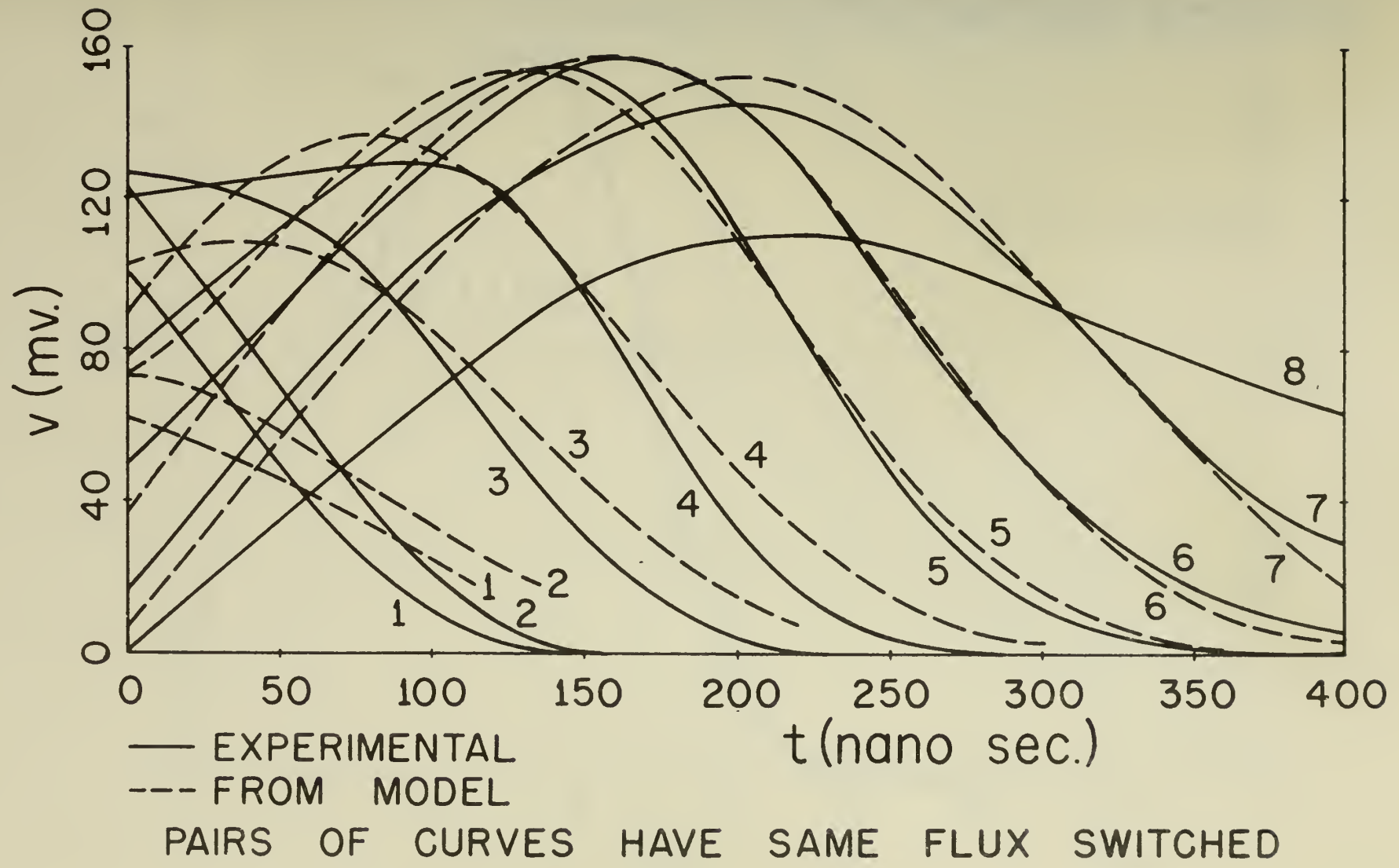


Figure 4 - Experimental and Calculated
Partial Switching Curves

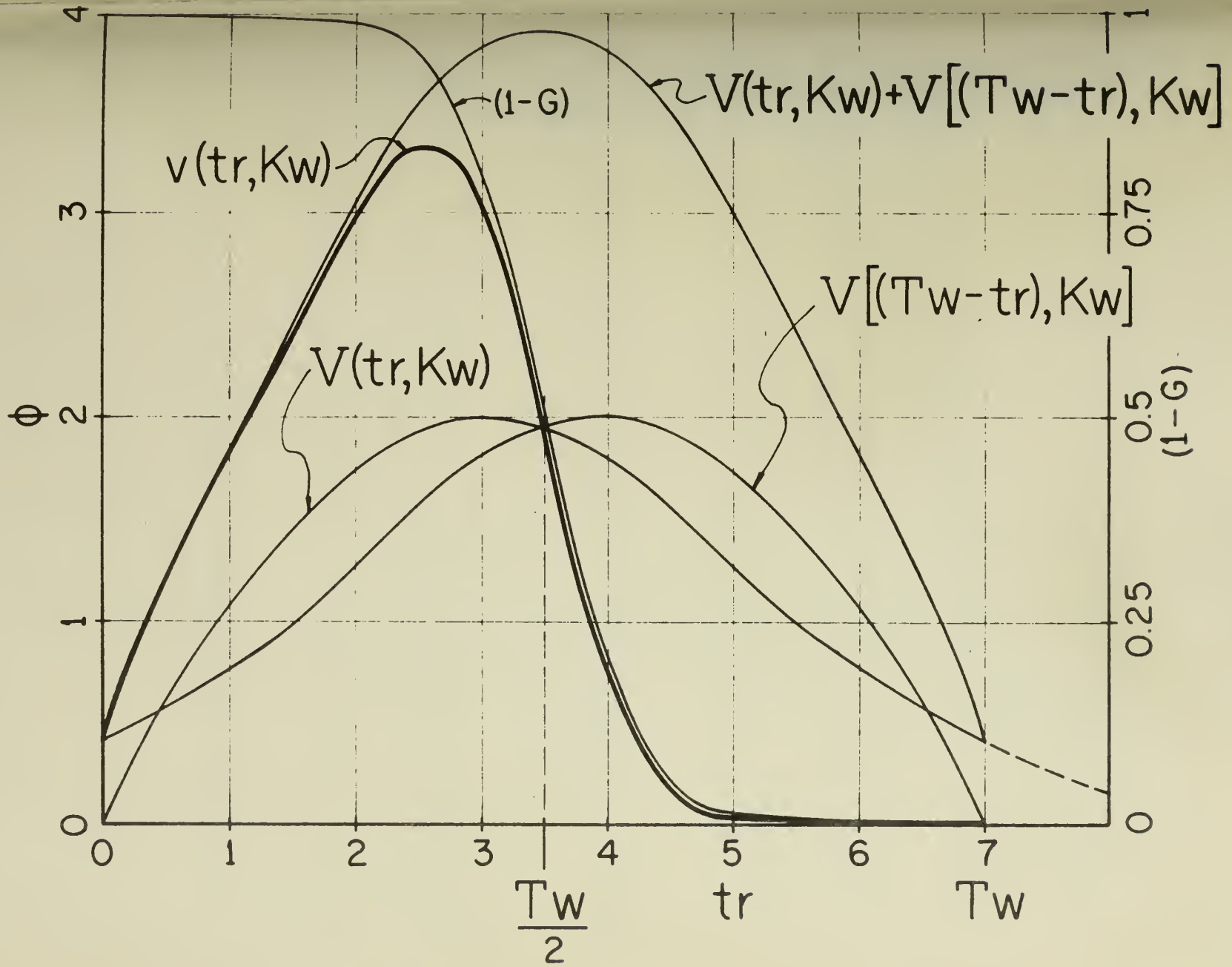


Figure 5 - Graphical Construction of a Partial Switching Curve

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